EXTENSIVE BOILING AS A PRECIPITATION MECHANISM FOR PRECIOUS & BASE METAL ORES, BIENAVENTURADA MINE, HUANCAVELICA, PERÚ

Ricardo Castroviejo*[1] *(ricardoc@minas.upm.es), José Andrés Yparaguirre*[2] *(joseandres54@hotmail.com), César Cánepa*[2] *(cfcanepa@terra.com.pe)
[1] Universidad Politécnica de Madrid, Spain
[2] Universidad Nacional Mayor de San Marcos, Lima, Perú

The Bienaventurada mine operates a polymetallic Ag-Pb-Zn (Cu, Au) vein system of the low sulphidation epithermal type. Fluid inclusions, FI, are abundant in quartz, sphalerite and adularia. FI petrography demonstrates typical primary growth zoning which occurs frequently in crystalline quartz, and defines the most common primary FI. These are usually very small, but several types of primary, P, and secondary, S, FI Assemblages (FIAs) comprising FI of measurable size (3 to > 100 μm) can also be identified through careful petrographic work. The fluids are aqueous and undersaturated, and no evidence of CO_2 was found; the degree of fill is usually high (~70-80 %) in the L-rich inclusions, but extremely low in V-rich inclusions. The measured microthermometric values are very consistent in the FIAs selected; they are for the most part roughly similar in the P and S assemblages: the median is typically ~258ºC for total homogenization temperatures, Th, and -1.5 ºC for ice melting temperatures, Tm (corresponding to 2.57 wt% NaCl eq). The widespread occurrence of L-rich and V-rich FI in the same FIA and the consistent Th values point to an extensive boiling system along the vein. In these conditions, Th equals T of trapping, and the ores are assumed to have been precipitated from an aqueous low salinity boiling fluid, of likely meteoric origin, at some 250-280º C, under ~500 m hydrostatic head.

The Bienaventurada vein system trends ~N60ºE, with steep SE dips, along some 3 km, at 4700 m asl (fig.1), and is worked underground along over 1500 m, down to 400 m depths (fig. 2). It occurs in a Miocene andesitic dome field, altered mainly to argillic and phyllic assemblages. Its width varies between 0.5 and 4 m, and it hosts Ag and base metal sulphide ores (sphalerite, freibergite, galena, pyrite, chalcopyrite, and scarce sulphosalts, as gratonite, selingmanite, jordanite, dufrenoysite, etc.) in a quartz, adularia, sericite gangue, with minor clay, barite, realgar, orpiment…*(9)*. The main FI-samples' location is shown in figure 2.

FI petrography shows three main generations of quartz (q1, q2, 13), and typical textures of low sulphidation epithermal deposits, with widespread primary growth zoning in euhedral q2 (fig. 3), usually related to the ore. Modified, recrystallized textures (fig. 5) are also observed, and related FI when found ("pseudoprimary" FI) have been discarded for microthermometric work *(4, 8)*. Most FI have been measured in q2 and in sphalerite (figs. 4 and 6), also rarely in adularia. Boiling is evidenced by vapour rich FI Assemblages, FIAs, or more typically by coexisting L-rich and V-rich FI, the former with constant L:V ratios and Th *(7)*. It is also suggested by the similarity in Th values in primary and secondary FIAs. The resulting values are represented in figs. 7 (Th) and 8 (ice melting). Measured values are consistent with petrographic observations and with the detailed analysis of FIAs *(5)*. Fig. 7 shows that most Th are distributed in a tight range, between 250 and 280 ºC. There is a minor range of values around 300-325 ºC, but careful observation of the

corresponding FIs shows that these coexist in the same FIA with Th values of ~260 ºC. This inconsistency suggests that the higher T are not valid, and due probably to later re-equilibration, as stretching or necking down. The median calculated for the whole group (266 ºC, fig. 7) is therefore not reliable; instead that of the main range, i.e. 258 ºC, should be considered. The overall Th distribution in the deposit is reflected by the palaeo-isotherms sketched in fig. 2: an inner core with T >270 ºC, and an outer enveloppe with 270< T > 250 ºC. Geochemical work in progress suggests that the shape of the geotherms is related to the ore-fluid flow, moving upwards and laterally from the thermal core. Boiling has been observed in most of the samples along the vein in the productive intervals. This suggests that boiling has been the main mechanism of ore precipitation, and that this happened between 250 and 280 ºC T, P ~ 41 b (hydrostatic regime), at shallow depths that for the mean salinity values found (2.57 wt% NaCl eq) are estimated as ~500 m hydrostatic head; fluid density ~ 0.8 g.cm^{-3} *(1, 2, 3, 6, 10)*.

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Figure captions

Figure 1.- Location of the Bienaventurada mine.
Figure 2.- Sketch of the vein and mining works, with location of FI samples and palaeo-isotherms.
Figure 3.- Primary growth zoning in quartz q2, lined with minute FI.
Figure 4.- Big (>0.1 mm) isolated, negative-crystal shaped, aqueous primary FI in sphalerite.
Figure 5.- Modified (feathery) texture, as a recrystallization crown on euhedral quartz.
Figure 6.- Tightly associated L-rich and V-rich FI in sphalerite, 10-20 μm in size.
Figure 7.- Histogram with measures of total homogenization temperatures, Th.
Figure 8.- Histogram with measures of ice melting depression (-Tf ºC).

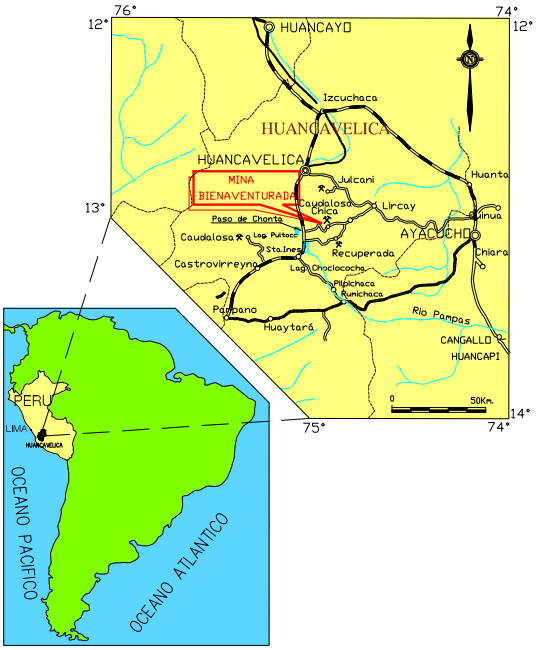

Figure 1

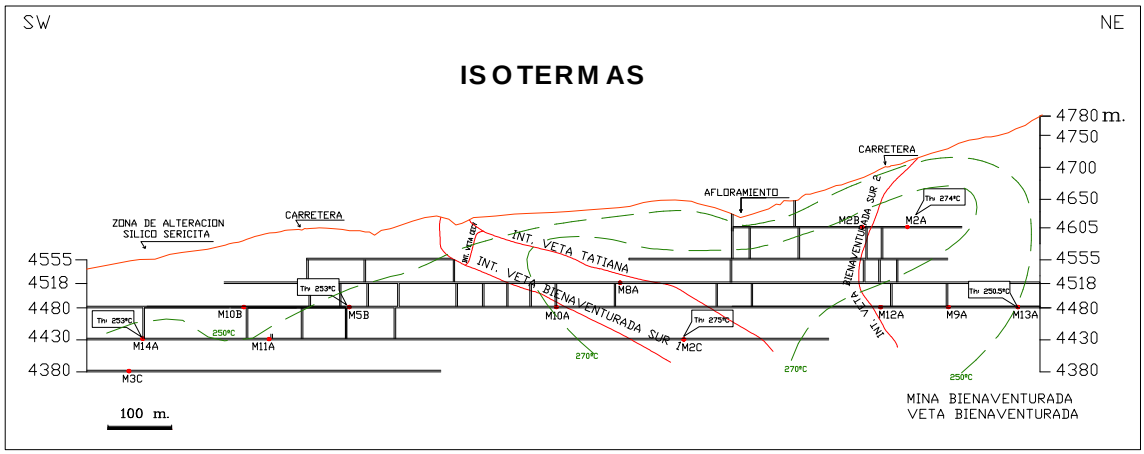

Figure 2

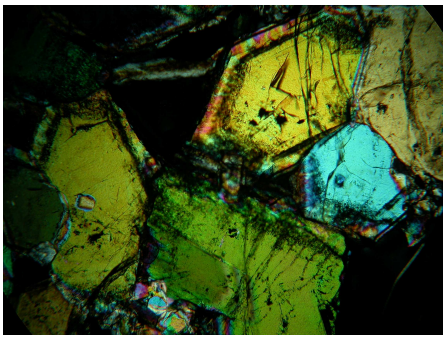

Figure 3

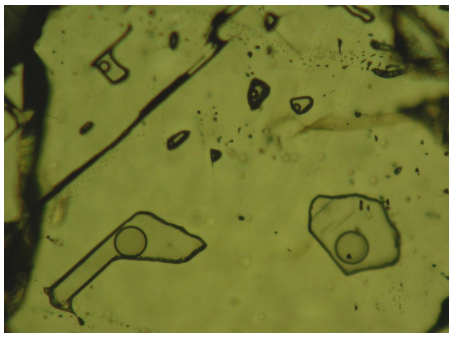

Figure 4

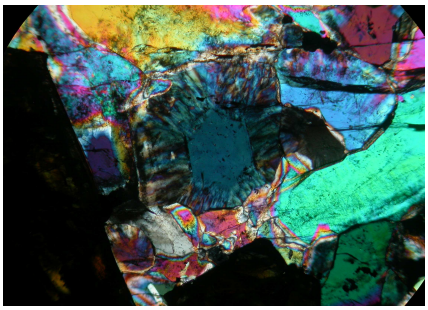

Figure 5

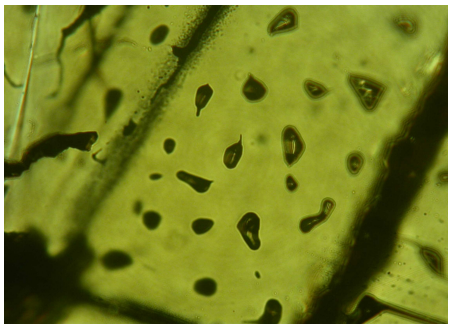

Figure 6

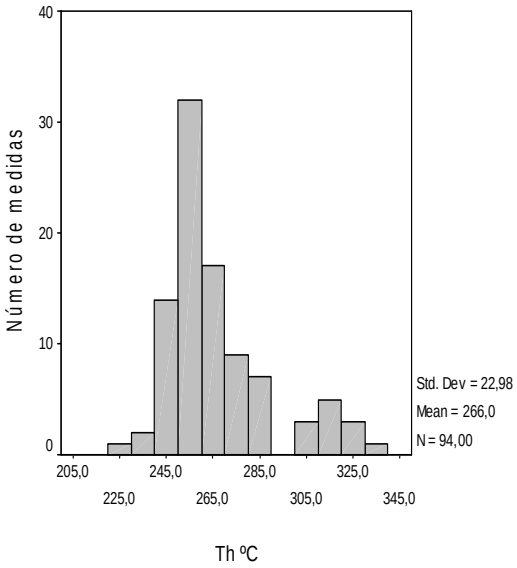

Figure 7

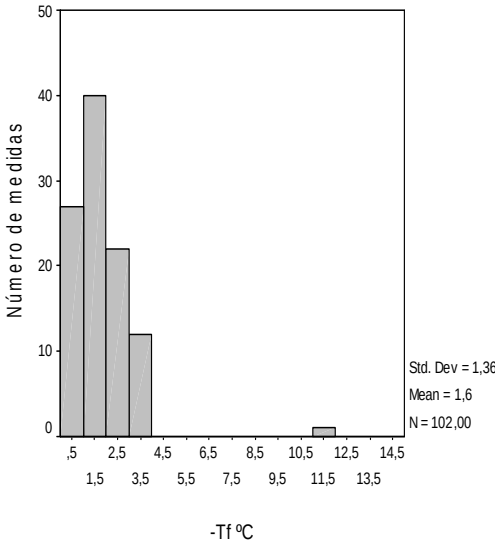

Figure 8